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RADIATION PROTECTION FACTORS OF SELECTED LIGHT VEHICLES AGAINST RESIDUAL RADIATION

HOWELL CATON
JOHN A. MORRISSEY

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U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

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This report summarizes calculations made to determine the factors needed to correct the in-vehicle Radiation Detection Identification and Computation Meter (RADIAC) dose readings to the outside environment. The methodology used is a modified VCS approach and is fully described. The VCS calculation produces a gamma protection factor for a 2 day old fallout spectrum lying on the ground surface exterior of the vehicle. This protection factor can be used to correct the in-vehicle RADIAC dose level readings to produce the exterior free-field dose level. The results present not only the correction factors but also several spectra comparisons for in-vehicle and exterior free-field. The calculated correction values are shown below. Keywords:

Vehicle	Correction Factor
HMMWV	1.7
M1008	2.0
M880	2.0

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I. Objective

The calculation of a correctional factor which could be used for the conversion of in-vehicle Radiation Detection Identification and Computation Meter (RADIACMETER) measurements to free-field radiation doses in the region external to the vehicle. The three light utility vehicles selected are listed below.

a. The Highly Mobile Multi-Wheeled Vehicle (HMMWV), Model M998

b. The Commercial Utility Cargo Vehicle (CUCV) ,Model 1008

c. The M880 1.25 Ton Cargo Truck

II. Background

After the detonation of a nuclear weapon, the surrounding area is known as the fallout region and has a gamma contamination created by the soil activation and the radioactive dust resulting from the detonation. The radiation levels decrease with time and the gamma energy spectrum shifts from an average energy of 1.0 MeV one hour after the detonation to 0.49 MeV two days later. Because of the planned installation of the RADIACMETER in selected vehicles to provide the crews with radiation dose measurements, it is necessary to have a factor to convert the in-vehicle dose rate to the external free-field environment. This conversion number is the gamma protection factor (GPF) and this report presents the methodology used for the calculations and the results for the three selected vehicles.

III. Methodology

1. The Gamma Protection Factor

The gamma protection factor (GPF) is the ratio of the free-field to in-vehicle dose rates as shown in equation 1 and is a measure of the radiation protection afforded by the vehicle from an external gamma source.

$$GPF = \frac{\text{free field gamma dose}}{\text{gamma dose to all extra-vehicular sources}} \qquad (1)$$

2. Source

The gamma source used for these calculations was a uniform semi-infinite plane and a two-day-old fallout spectrum which represented the radioactive ground external to the truck. Table 1 is a listing of the two day fallout spectrum normalized into 21 energy groups.

TABLE 1. Two Day Fallout Energy Spectrum

Energy Group	Upper Energy (eV)	Fallout Spectrum Gammas per Group
1	1.4(+7)*	-
2	1.0(+7)	-
3	8.0(+6)	-
4	7.0(+6)	-
5	6.0(+6)	-
6	5.0(+6)	1.94(-8)
7	4.0(+6)	3.65(-6)
8	3.0(+6)	5.65(-4)
9	2.5(+6)	2.28(-3)
10	2.0(+6)	1.49(-2)
11	1.5(+6)	4.70(-2)
12	1.0(+6)	1.77(-1)
13	7.0(+5)	2.93(-1)
14	4.5(+5)	6.98(-2)
15	3.0(+5)	2.17(-1)
16	1.5(+5)	4.94(-2)
17	1.0(+5)	2.28(-2)
18	7.0(+4)	3.02(-2)
19	4.5(+4)	4.48(-2)
20	3.0(+4)	2.99(-2)
21	2.0(+4)	-
	total	1.0

* (+7) = $x\ 10^{+7}$

3. Calculational Technique

The GPFs for the vehicles were calculated using the radiation transport computer code, MORSE. MORSE simulates the generation of radiation source particles by using a random number generator to select particles from the source energy distributions (Table 1). The flight path of each particle is simulated by using a random number generator to select the particle path direction and the material interaction based on an input set of cross sections. Each particle is moved and tracked from the source until it either escapes the region of interest, enters the detector area, or is dropped by the calculation because the particle is statistically improbable. A particle that enters the detector is scored by weighting it with a gamma dose response function which describes energy deposition as a function of particle energy for a particular material. Human tissue kerma is the dose response curve used for this calculation.

The MORSE code can also be used in the "adjoint" mode in which particles are tracked from detector to source. In this mode the dose response function is used as the source distribution, the scattering matrix is transposed and particles are scored by their weight in the normalized source energy distribution. The adjoint mode was selected for this study because the physical situation of a point detector and a distributed source makes it the more efficient method.

A modification of adjoint MORSE, called the Vehicle Code System (VCS)[1] is used at the Ballistic Research Laboratory (BRL) to determine vehicle radiation protection factors.'[2] For initial radiation calculations, the radiation transport problem is separated into two major calculations. A discrete ordinates solution of the Boltzmann Equation for the fluence in the vicinity of the target resulting from the weapon burst is obtained with the DOT computer code.[3] The free-field flux is recorded on a binary tape known as a VISA tape, in 48 solid angle bins to account for anisotropy. A special version of adjoint MORSE,[4] called MIFT,[5] is used to provide an importance function at a surface surrounding the target structure. The MIFT code uses the GIFT geometry code which has been incorporated into the MORSE code at the BRL. The importance function is a measure of the probability that either a particle existing at the surrounding surface or its produced secondary particle will reach the crew in the vehicle. The fluence and the dose at the detector position

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1. W.A. Rhoades, *Development of a Code System for Determining Radiation Protection of Armored Vehicles (U)*, Oak Ridge National Laboratory, ORNL-TM-4664 (1974). (UNCLASSIFIED)

2. W.A. Rhoades, M.B. Emmett, G.W. Morrison, J.V. Pace, III and L.M. Petrie, *Vehicle Code System (VCS) User's Manual (U)*, Oak Ridge National Laboratory, ORNL-TM-4648 (1974). (UNCLASSIFIED)

3. F.R. Mynatt, F.J. Muckenthaler and P.N. Stevens, *Development of Two-Dimensional Discrete Ordinates Transport Theory for Radiation Shielding (U)*, Union Carbide Corporation (Nuclear Division), CTC-INF-952 (1969). (UNCLASSIFIED)

4. M.B. Emmett, *The MORSE Monte Carlo Radiation Transport Code System (U)*, Oak Ridge National Laboratory, ORNL-4972 (1975). (UNCLASSIFIED)

5. A.E. Rainis and R.E. Rexroad, *MIFT: GIFT Combinatorial Geometry Input to VCS Code (U)*, Ballistic Research Laboratory No. 1967 (1977). (AD #A037898) (UNCLASSIFIED)

are obtained by a code named the Detector Response Code (DRC) which combines the output of the DOT and MIFT calculations.

For this work, a modified form of VCS which performed an adjoint calculation was used instead of MORSE. Adjoint particles were followed from a detector position within the vehicle, 1.35 meters above the ground plane and scored when they intersected the ground plane. The free-field tissue kerma dose at the same detector position was determined by making a similar calculation with the vehicle absent.

For the calculations, an existing weapon spectrum VISA tape was altered to reflect the fallout spectrum and was used as source input. To eliminate the strong angular biases which might exist in a modified weapon spectrum, the calculations for each vehicle were performed for the four principle exposures (front, left side, right side, rear) with respect to the source direction. The dose level used to calculate the GPF for each vehicle was the calculated dose averaged over the four exposures for each vehicle.

The detector position for these calculations was high in the rear portion of the cab, centrally located with respect to the sides of the vehicle. During the HMMWV study a sensitivity study to determine the effect of detector position on the dose calculation was performed. For this study five calculations were made with five different detector positions within a ten centimeter radius of that detector position selected for the final HMMWV dose calculation. The results showed that the calculated dose did not vary more than 3% for any of these detector positions.

For all calculations the vehicles were considered to have their cargo hauling beds empty.

IV. Vehicle Descriptions

1. The HMMWV

The HMMWV is a 1.25 ton payload vehicle designed to perform multiple mission roles for the Armed Services. The vehicle has several configurations among which are personnel carrier, cargo carrier, weapons carrier and ambulance. The version used for this calculation was the M998 cargo carrier with canvas enclosure. Figures 1 and 2 show front view and side view of the vehicle, respectively.

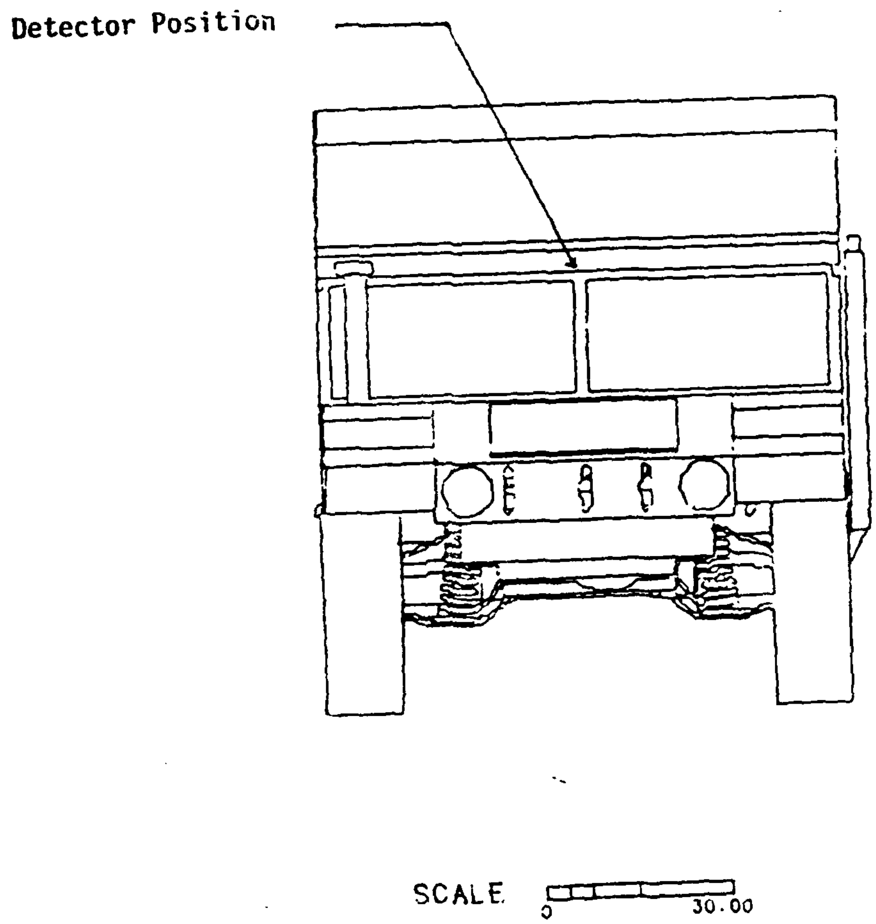


Figure 1. HMMWV (Model M998) Front View

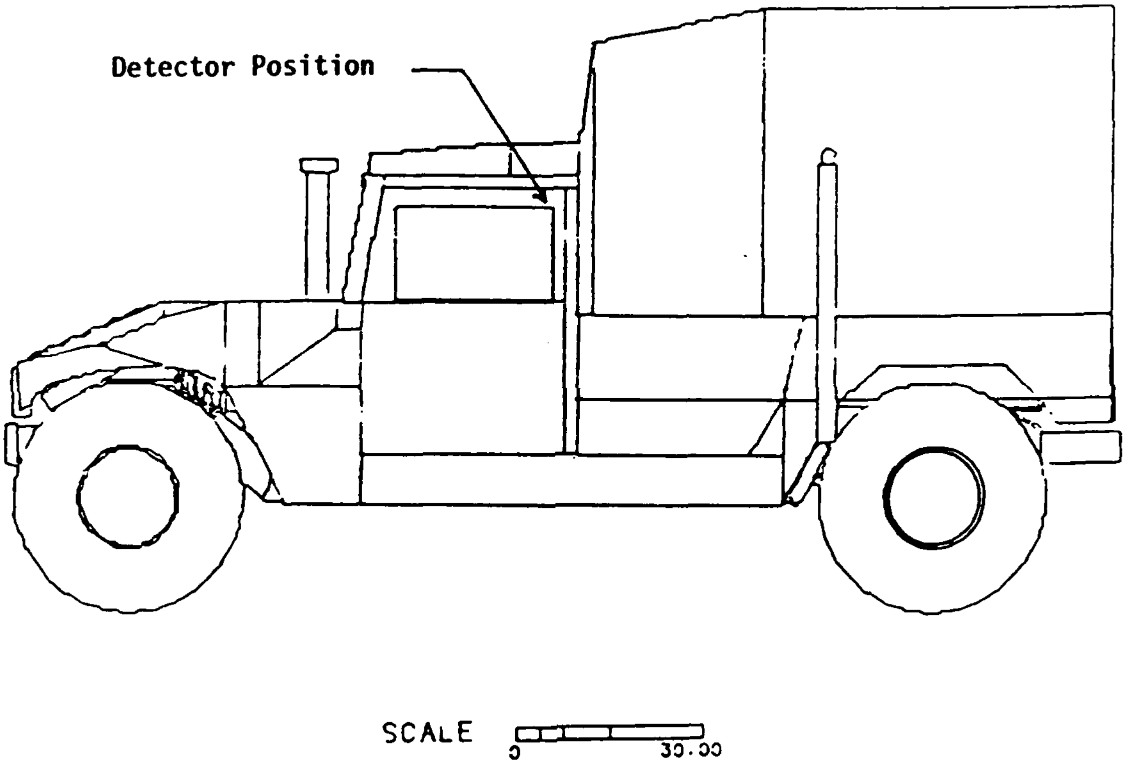


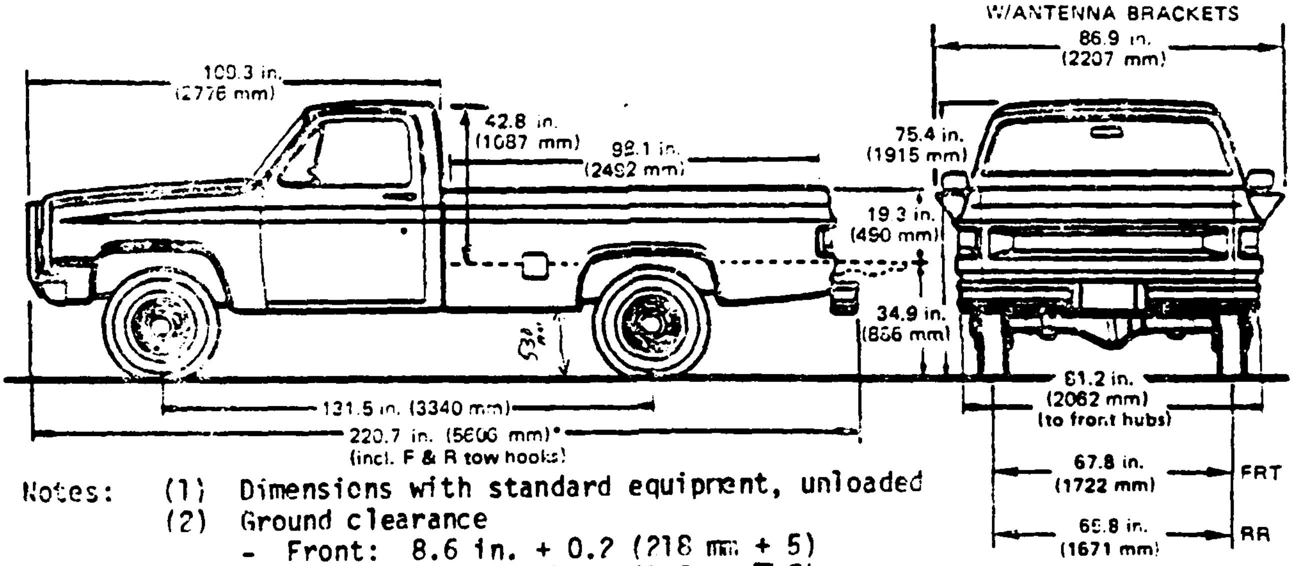
Figure 2. HMMWV (Model M998) Side View

2. **The CUCV (Model M1008)**

The M1008 is one of the CUCV family of light duty trucks which has several performance roles for the U.S Army, including cargo transport, troop transport, ambulance service, and utility service. It is the military version of Chevrolet's 5/4 ton, 4x4, K30903 pickup and comes equipped with a troop seat kit and a cargo box cover kit as shown in Figure 3.

3. **The M880**

The M880 is the military version of a Dodge 5/4 ton (4x4) pickup truck and it is shown if Figure 4. The uses of this vehicle are the same as those mentioned for the M1008 in the previous section.



Notes: (1) Dimensions with standard equipment, unloaded
(2) Ground clearance
- Front: 8.6 in. + 0.2 (218 mm + 5)
- Rear: 7.8 in. ± 0.2 (198 mm ± 5)

Figure 3. The CUCV (Model M1008)

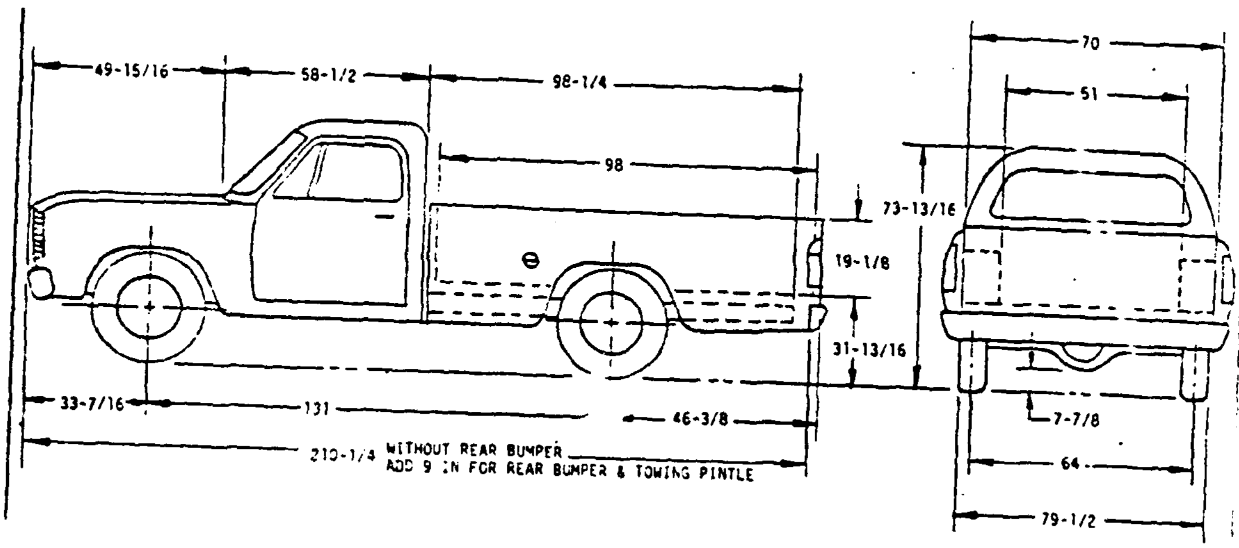


Figure 4. The M880 Truck

V. Results

1. Correction Factors

The calculated dose levels for the three vehicles are listed in Table 2. For each vehicle, the data for the four different orientations to the source are given along with the average and the GPF (RADIAC correction number).

TABLE 2. Calculated Dose Levels and GPF for All Vehicles

Orientation to Source	Free-field Dose Rads/Source Gamma	In-vehicle Dose Rads/Source Gamma
HMMWV		
Front	1.85(-11)	9.33(-12)
Left Side	1.87(-11)	1.10(-11)
Rear	1.90(-11)	1.18(-11)
Right Side	1.89(-11)	1.13(-11)
Average	1.88(-11)	1.09(-11)
Gamma Protection Factor is $\frac{1.88(-11)}{1.09(-11)} = 1.7$		
CUCV (Model M1008)		
Front	1.85(-11)	8.7(-12)
Left Side	1.87(-11)	9.9(-12)
Rear	1.90(-11)	1.05(-11)
Right Side	1.89(-11)	9.3(-12)
Average	1.88(-11)	9.6(-12)
Gamma Protection Factor is $\frac{1.88(-11)}{9.6(-12)} = 2.0$		
M880		
Front	1.85(-11)	5.8(-12)
Left Side	1.87(-11)	9.8(-12)
Rear	1.90(-11)	1.19(-11)
Right Side	1.89(-11)	9.8(-12)
Average	1.88(-11)	9.3(-12)
Gamma Protection Factor is $\frac{1.88(-11)}{9.3(-12)} = 2.0$		

2. In-vehicle and Free-Field Spectra

As part of the calculation, the gamma energy spectrum at the detector position can be studied. Table 3 lists the normalized calculated free-field and in-vehicle spectra for the HMMWV vehicle with a frontal orientation to the source. These same calculations were performed for all vehicles but because the data were essentially the same, only the HMMWV results are presented.

TABLE 3. HMMWV Free-Field and In-Vehicle Spectra at the Detector

Energy Group	Upper Energy (eV)	Fallout Spectrum Gammas per Group	
		Free-Field	In-Vehicle
1	1.4(+7)	-	-
2	1.0(+7)	-	-
3	8.0(+6)	-	-
4	7.0(+6)	-	-
5	6.0(+6)	-	-
6	5.0(+6)	9.68(-10)	1.35(-9)
7	4.0(+6)	2.82(-7)	2.85(-7)
8	3.0(+6)	4.35(-5)	5.14(-5)
9	2.5(+6)	4.30(-4)	3.04(-4)
10	2.0(+6)	1.74(-3)	2.20(-3)
11	1.5(+6)	9.17(-3)	1.04(-1)
12	1.0(+6)	5.63(-2)	5.57(-2)
13	7.0(+5)	1.70(-1)	1.40(-1)
14	4.5(+5)	6.24(-4)	6.47(-2)
15	3.0(+5)	4.09(-1)	4.05(-1)
16	1.5(+5)	1.27(-1)	1.64(-1)
17	1.0(+5)	5.65(-2)	8.19(-2)
18	7.0(+4)	5.11(-2)	5.20(-2)
19	4.5(+4)	4.18(-2)	2.31(-2)
20	3.0(+4)	1.46(-2)	3.50(-3)
21	2.0(+4)	7.75(-5)	6.71(-5)
	total	1.0	

3. Analysis

Fallout radiation measurements were previously performed on the M548 cargo carrier[6] in 1971. The M548 is a tracked vehicle

with steel doors but otherwise differs little from the HMMWV. The M548 was exposed to a Cobalt 60 source with an average gamma energy of 1.25 MeV and the measured GPFs ranged from 1.5 - 1.6. When the source energy and vehicular construction differences are considered, there is reasonable agreement between the calculated protection factor for the HMMWV and the experimentally determined protection factor for the M528.

Figure 5 is a graphical representation of the dose as a function of gamma energy for free-field and in-vehicle calculations. As one would expect, the graph shows a significant decrease in the dose effect of the low energy gammas (<0.045 MeV). This decrease can be attributed to the attenuation of the vehicle material. Also, the graph shows an increase in the dose effect of gamma with energies in the 0.07 to 0.15 range. This decrease can be attributed to the down scatter of the higher energy gammas by the vehicular material.

VI. **Summary**

Table 5 lists the protection factors for all the vehicles investigated.

TABLE 4. Summary of the Results

Vehicle	Correction Factor
HMMWV	1.7
M1008	2.0
M880	2.0

All three vehicles which were analyzed have similar dimensions and the detector height above ground for all calculations was essentially the same. However,the construction for each vehicle was different. The HMMWV was fabricated of aluminum while the M1008 and the M880 each have a steel chassis. Because of the metal thickness difference, the mass per unit area remains constant and thus the shield factors are similar. A large

6. Murray A Schmoke and Ralph E. Rexroad, *Fallout Shielding Characteristics of Combat Vehicles, M548 Cargo Carrier, XM551 Armored Reconnaissance Vehicle, and M728 Combat Engineer Vehicle,* Report No. 1529, Ballistic Research Lab., Aberdeen Proving Ground, Md. 21005 (AD881453L)

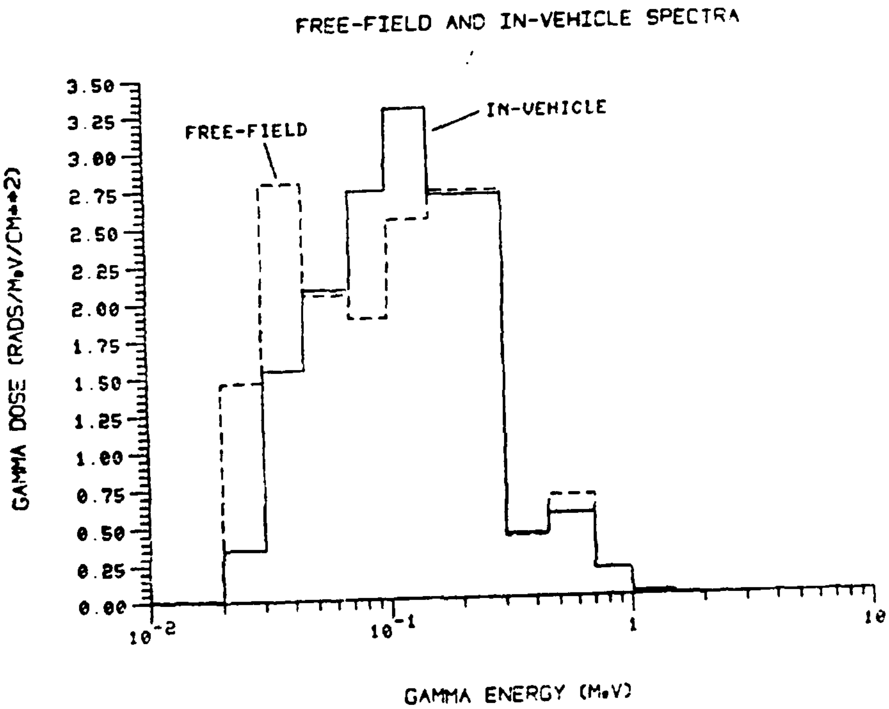


Figure 5. Free-field Spectrum versus In-vehicle Spectrum

contribution to the protection factor difference is caused because the HMMWV has a canvas roof, which affords no gamma protection while the cabs of the M1008 and M880 are complete metal enclosures.

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